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Factsheet

SOIL ACIDITY AND LIMING

(Revision of Factsheet "Soil Acidity and Liming", November 1985)

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The pH scale ranging from 0 to 14 is used to indicate acidity and alkalinity. A pH of 7.0 is neutral, values below 7.0 are acid, and those above are alkaline. The lower the pH, the more acid is the soil. The higher the pH, the more alkaline.

The pH values of some common items are: pure water, 7.0; lemon juice, 2.2 to 2.4; orange juice, 3.4 to 4.0; fresh milk, 6.3 to 6.6; mild soap solution, 8.5 to 10.0; most Ontario soils, 4.5 to 8.0.

IMPORTANCE OF pH IN SOILS

Soil pH is imporant chiefly because of the many effects it has on biological and chemical activity of the soil. The effect of pH on plant growth can be very large but is usually indirect through biological and chemical factors.

Acid sandy soils are low in magnesium and frequently in calcium. Calcium is the most important neutralizing element. As calcium and magnesium are depleted by leaching and plant uptake, hydrogen and aluminum ions become more prevalent, and the soil becomes acid.

Phosphorus in soils is commonly considered to be most available at pH values near 6.5, with the availability decreasing at both lower and higher pH values. However, soil test fertilizer and crop response studies in Ontario indicate that even many of the high pH soils (up to pH 7.9) contain adequate amounts of plant available phosphorus.

Aluminum, iron, manganese, boron, copper and zinc are more available to plants in acid than in neutral or slightly alkaline soils. When a soil is made less acid (more alkaline) by liming, the availability of manganese in particular can decrease substantially. It is therefore important not to apply more lime than necessary.

Iron, manganese, zinc, copper and boron are essential to plant growth, but are required in very small amounts. If deficient, they reduce yield. In acid soils, manganese may be toxic and result in reduced crop yields. Aluminum is not needed for plant growth and in acid soils it can be quite toxic to plants. Molybdenum is one element essential for plants which is more available in alkaline (high pH) soils.

Soil pH affects crops in other ways. Legumes, such as alfalfa, trefoil, clovers and soybeans, have bacteria living in nodules on their roots which take nitrogen from the air and change it into a form used by plants. Some strains of the bacteria thrive best at pH values above 6.0. Hence this range is best for many legume crops. Potato scab is more prevalent at soil pH values above 5.5 than at lower values, although potatoes grow well in high pH soils. Club root in cole crops such as cabbage is less prevalent at pH values of 7.2 or higher. Black rootrot in tobacco is more prevalent at pH values above 6.4. Some plants such as rhododendrons and blueberries grow well only at pH values below 5.5 and appear to suffer from iron and/or manganese deficiencies at higher pH values. There is also evidence that fungi associated with healthy root development on these plants require a low pH. On the other hand, most field crops grow best in soils with a wide pH range of 5.5 to 8.0. Aluminum and manganese can be toxic for common field and vegetable crops at soil pH values below 5.0.

HOW SOILS BECOME ACID

Soils are alkaline when they are high in basic ions, mainly calcium and magnesium and to a lesser extent potassium and sodium. Most soils in southern Ontario were formed from dolomitic or calcitic limestone high in calcium and magnesium and were therefore alkaline when formed. Many soils in northern Ontario were formed on materials low in these "bases" such as granite, and these soils tend to be acid.

As leaching removes calcium, magnesium and potassium from soils over hundreds or thousands of years the natural trend is for soils to become more acid. The addition of acid forming fertilizers, chiefly nitrogen greatly increases the rate at which soils become acid (Table 1). The effect of nitrogen fertilizer on soil pH in Ontario is shown in Table 2.

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Table 1. Lime Required to Neutralize the Acidity Generated by Some Common Fertilizer Materials*

Material	Analysis %	Each 100kg (lb)** of fertilizer material	Each kg (lb)** of Nitrogen (N) supplied by the fertilizer material
Ammonium nitrate	34-0-0	60	1.8
Urea	45-0-	81	1.8
Anhydrous ammonia	82-0-0	148	1.8
Aqua ammonia	20-0-0	36	1.8
Nitrogen solution	28-0-0	50	1.8
Sulfate of ammonia	21-0-0	110	5.4
Monoammonium phosphate	12.5-50-0	65	5.0
Diammonium phosphate	18-46-0	90	5.0
Superphospate	0-20-0	0	0
Triple superphosphate	0-46-0	0	0
Muriate of potash	0-0-60	0	0
Sulfate of potash	0-0-50	0	0
Sulfate of potash magnesia	0-0-21 (10 Mg)	0	0

* *Adaped from Andrews, "The response of Crops and Soils to Fertilizers and Manures", 2nd Ed., 1954*

** *Either kilograms or pounds may be used in this table provided the same units are used in both columns.*

Table 2. Effect of Nitrogen Applied Annually to Corn on Soil pH of the Top 15 cm (6 in.) Layers on Two Soils after Five and Fifteen Years

Annual nitrogen rate kg/ha	Soil pH
	Sandy loam soil* 5 years
0	6.4
112	6.0
224	5.4
336	4.6
	Clay loam soil** 15 years
0	5.4
298	4.7
332	4.4
0 (Alfalfa)	5.2

* *Personal communication W.I. Findlay, Agriculture Canada, Harrow, Ontario*

** *E.F. Bolton, J.A. Aylesworth and W.I. Findlay, 1970, Can. J. Soil Sci. 50: 260-261.*

Acid rain contributes to the acidity of Ontario soils but the acidity caused by rainfall in Ontario in a year is much less than that from the use of nitrogen fertilizers.

Many Ontario soils with pH values above 7.0 contain small particles of calcium and magnesium carbonate which replenish the supply of basic ions as calcium and magnesium are removed by leaching and crop removal. The addition of nitrogen fertilizers has essentially no long term effect on the pH of these soils, and will not have until the calcium and magnesium carbonate have been depleted. On most of these soils this will take many years.

AREAS OF ACID SOILS IN ONTARIO

The largest area of acid soils in southern Ontario has been in the clays of Haldimand couny and the regions of Niagara North and South. Smaller localized areas extend into Wentworth, Halton and Peel counties and westward into the sandy loam areas of Norfolk, Elgin, Kent and Essex. The sandy soils of the Lake Erie counties have become increasingly acid in recent years, with some of the lowest pH values in the province (as low as 3.2) now appearing in these soils. Prescott, Russell and Frontenac counties in Eastern Ontario have an appreciable proportion of acid soils, with smaller areas in adjacent counties. All districts of northern Ontario have a high proportion of acid soils with the exception of Rainy River and the clay belts of Temiskaming and Cochrane.

LOW pH SPOTS

There have been frequent occurrences of low pH spots in farm fields in southwestern Ontario where the average pH of the field indicates no lime required. These areas usually occur where there are course-textured (sandy) spots in fields that are predominantly fine textured (clay or clay loam). Areas having a pH as low as 3.2 have been observed in fields where the average pH was above 6.0.

It is recommended that soil tests be made every two to three years to check pH, as well as fertility levels. Where the soil texture is not uniform in a field, the coarser-textured areas (or any problem areas) should be sampled separately.

CORRECTION OF SOIL ACIDITY

Acid soils usually result in poor yields of crops so liming to neutralize the acidity is frequently essential for profitable crop production (Table 3). In the example shown in Table 3 the application of 7 t of lime/ha returned $108/ha over the cost of lime in the first year based on corn at $118/t and lime at $25/t spread. With the lime paid for in the first year the 2.4 tonnes/ha yield increase in subsequent years would be entirely profit. The lime is expected to last for at least five and commonly 10 years.

To correct soil acidity ground limestone should be broadcast and worked into the soil at rates determined by soil test.

Table 4 shows the soil pH values below which lime is recommended and the "target" soil pH to which soils should be limed for different crops. In Ontario most crops grow quite well at pH values higher than the target pH to which lime is recommended.

Table 3: The effect of dolomitic limestone on corn yields, soil pH, and soil magnesium levels on an acid sandy loam soil, 1975-1978*

Rates of Limestone t/ha	Grain yield t/ha	Soil pH 1st Year	Soil pH 4th Year	Soil Mg ppm 1st Year
0	5.0	4.3	4.5	33
7	7.4	5.5	5.7	175
13	8.0	6.0	5.8	200+
20	7.9	6.3	6.3	200+
27	8.1	6.4	6.5	200+

* *From R.W. Johnston, Ridgetown College of Agricultural Technology*

Table 4. Soil pH Below Which Lime is Recommended for Ontario Field Crops

Crops	Soil pH Below Which Lime is Recommended	Target Soil pH*	
Coarse and Medium Textured Mineral Soils (sands, sandy loams, loams and silt loams) Perennial legumes,oats, barley, wheat triticale, beans, peas, canola, flax	6.1	6.5	
Corn, soybeans, rye, grass hay, pasture and tobacco.	5.6	6.0	
Fine Textured Mineral Soils (clays and clay loams)			
Alfalfa	6.1	6.5	
Other perennial legumes, oats, barley, wheat, triticale, soybeans, beans, peas, canola, flax.	5.6	6.0	
Corn, rye, grass hay, pasture and tobacco.		5.1	5.5
Organic Soils (peats and mucks)			
All field crops	5.1	5.5	

** Where a crop is grown in rotation with other crops requiring a higher pH (for example corn in rotation with wheat or alfalfa) it is recommended that the soil be limed to the higher pH.*

THE BUFFER pH

Different soils with any one pH value, for example 5.2, will require different amounts of lime to bring the pH to a particular desired level depending chiefly on the clay and organic matter content. The soil pH is used to determine which soils need to be limed but a separate soil test, the buffer pH, is run on soils needing lime to determine the amount of lime required. For soils needing lime (based on soil pH) table 5 may be used to determine from the buffer pH the amount of lime required to reach the "target" soil pH value required for a specific crop.

Table 5. Lime Requirements to Correct Soil Acidity Based on Soil pH and Buffer pH

Buffer pH	Target Soil pH = 7.0*	Target Soil pH = 6.5 (Lime if soil pH below 6.1)	Target Soil pH = 5.0 (Lime if soil pH below 5.6)	Target Soil pH = 5.5 (Lime if soil pH below 5.1)
Lime required – t/ha (Based on an Agricultural Index of 75)				
7.0	2	2	1	1
6.9	3	2	1	1
6.8	3	2	1	1
6.7	4	2	2	1
6.6	5	3	2	1
6.5	6	3	2	1
6.4	7	4	3	2
6.3	8	5	3	2
6.2	10	6	4	2
6.1	11	7	5	2
6.0	13	9	6	3
5.9	14	10	7	4
5.8	16	12	8	4
5.7	18	13	9	5
5.6	20	15	11	6
5.5	20	17	12	8
5.4	20	19	14	9
5.3	20	20	15	10
5.2	20	20	17	11
5.1	20	20	19	13
5.0	20	20	20	15
4.9	20	20	20	16
4.8	20	20	20	18
4.7	20	20	20	20
4.6	20	20	20	20

** Liming to pH 7.0 is recommended only for club-root control on cole crops.*

LIME APPLICATION AND TILLAGE

Lime is not effective unless it is mixed with the soil. It should be applied evenly and worked in 15 cm (6 inches) deep. Lime recommendations presented here should raise the pH of the top 15 cm of a soil to the listed target pH. If the soil is tilled to a greater depth than 15 cm proportionately more lime is required to reach the same target soil pH. Where tillage depths are reduced, rates of lime application should be reduced proportionately. More frequent liming will be needed.

LIME QUALITY

Two main factors affect the value of a particular lime for soil application. One of these is the amount of acid a given quantity of the lime will neutralize when it is totally dissolved. This is called the "neutralizing value" and is expressed as a percentage of the neutralizing value of pure calcium carbonate. A lime which will neutralize 90% as much acid as pure calcium carbonate is said to have a neutralizing value of 90. In general, the higher the calcium and magnesium content of a lime the higher the neutralizing value.

The second factor which affects the value of lime as a neutralizer of acidity is the particle size. Limestone gravel has much less surface area to react with acid soil than finely powdered limestone and, hence, it neutralizes acidity much more slowly; so slowly that it is of little value. The calculation of the fineness rating for ground limestone is illustrated in Table 6.

Table 6. Example Calculation of the Fineness Rating of a Liming Material

Particle Size	%of Sample	Effectiveness Factor	
Coarser than no. 10 sieve[1]	10	x 0	= 0
No. 10 to No. 60 sieve	40	x 0.4	= 16
Passing through no. 60 sieve	50	x 1.0	= 50
Fineness Rating			= 66

[1] A no. 10 tyler sieve has wires spaced 2.0 and a no. 60 Tyler sieve spaced 0.25 mm apart

THE AGRICULTURAL INDEX IS USED TO COMPARING LIME MATERIALS

Some means of combining the Neutralizing Value and the Fineness Rating is needed to compare various liming materials that are available. The index which has been developed in Ontario to do this is called the "Agricultural Index".

$$\text{The Agricultural Index} = \frac{\text{neutralizing value x fineness rating}}{100}$$

The Agricultural Index can be used to compare the relative value of different limestones for neutralization of soil acidity[1]. Lime with a high Agricultural Index is worth proportionately more than lime with a low index because it may be applied at a lower rate. If two ground limestones, A and B, have Agricultural Indices of 50 and 80 respectively,

[1]The Agricultural Index does not provide information about magnesium content. *Dolomitic lime should be used on soils low in magnesium.*

the rate of application of lime A required for a particular soil will be 80/50 times the rate required for lime B. Lime A spread on your farm is worth 50/80 of the price of lime B per tonne.

ADJUSTING APPLICATION RATES

Recommendations from the Ontario soil test service are based on lime with an Agricultural Index of 75. If you know the Agricultural Index of the lime you will use, you can calculate a rate of application specifically for liming material of that quality. This can be done using the following equation:

$$\text{Rate of Lime application from soil test report} \times \frac{75}{\text{Agr. Index of your lime}} = \text{Recommended rate of application of your lime}$$

For example if you have a lime requirement by soil test of 9 t/ha, and your most suitable source of limestone from a quality and price standpoint has an Agricultural Index of 90, you should apply 9 x 75/90 = 7.5 t/ha.

When you buy lime you should insist that the supplier provides the Agricultural Index or the information required to calculate it. You need this information to determine the application rate. The supplier is required by law to provide the neutralizing value and particle size.

LIMING MATERIALS

Calcitic limestone is almost pure calcium carbonate. Dolomitic limestone contains considerable magnesium carbonate and, on acid soils, is a good source of magnesium for plant growth. Usually the least expensive and the most effective way of supplying magnesium to soils needing lime is by applying dolomitic lime (high in magnesium) as shown in Tables 3 and 7. For soils used for growing tobacco, only dolomitic lime is recommended.

Table 7. The effect of Ground Dolomitic Limestone and Potash Fertilizer on Magnesium Content of Corn Seedlings on a Sandy Loam Soil with pH 4.5*. (Limestone applied May 27, 1976, corn sampled June 24, 1976)

Dolomitic Lime	Potash (K_2O) – kg/ha					
t/ha	0	45	90	134	180	Ave.
	Plant Magnesium – %					
0	0.27	0.30	0.22	0.21	0.23	0.25
7	0.73	0.58	0.46	0.41	0.37	0.51
13	0.75	0.62	0.57	0.49	0.46	0.58
20	0.90	0.62	0.55	0.54	0.52	0.63
Ave.	0.66	0.52	0.47	0.41	0.40	

* *R.W. Johnston Ridgetown College of Agricultural Technology.*

"Liquid lime" is advertised and occasionally sold in Ontario often at very high costs in relation to the neutralizing value. This is very fine ground limestone suspended in water. It is equivalent to finly ground dry lime in availability and would have a "fineness" rating of 100. When diluted with water the neutralizing value will be low per unit of weight resulting in the need for high rates of application. Note that in the fineness rating lime passing through a 60 mesh screen is considered to be 100% effective. Limestone ground finer than this is not considered to be any more effective.

When limestone is heated to form calcium or magnesium oxide it is called "burned lime", and when moisture is applied to the burned lime it becomes "hydrated lime" (calcium or magnesium hydroxide). Burned and hydrated lime have higher neutralizing values and are also more soluble than ground limestone. However, they are caustic and will burn plants. If used, they should be applied at least one month before seeding. Both of these forms are usually considerably more expensive than ground limestone.

Another liming material used occasionally is marl. Marl, which occurs in some swamps, is soft calcium-carbonate mixed with varying amounts of clay and organic matter. Usually it is more economical to buy ground limestone than to dig marl from a swamp, and then dry and crush it.

LOWERING SOIL pH

On soils with pH values below 7.0 it is possible to lower the pH (make the soil more acid) by adding sulfur or aluminum sulfate, but this is not necessary for most crops and it hastens the time when lime will be required. If the soil pH is above 7.0 it is not advisable and also usually quite impractical to lower the soil pH because of the very large amounts of sulfur or aluminum sulfate required.

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